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Agenda

• Current OpenCL™ scheduling model
• GPU Daemon:
  - Instant Mode
  - Enqueue Mode
• Performance Data
• Efficient use of GPU Daemon patterns
• Summary
Agenda

• Current OpenCL™ scheduling model

• **GPU Daemon:**
  - Instant Mode
  - Enqueue Mode

• Performance Data

• Efficient use of GPU Daemon patterns

• Summary
Current OpenCL™ scheduling model

- **Application**
  - clEnqueueNDRange
  - clWaitForEvents

- **Graphics Driver Stack**
  - UMD Runtime
  - Submit 137 us (59%)

- **Graphics Processing Unit**
  - KMD/OS
  - Threads Creation
  - Threads Execution
  - Cleanup Signal
  - GPU Start
  - GPU End

**Table:**

<table>
<thead>
<tr>
<th>Submission latencies</th>
<th>CPU Start to Queue</th>
<th>Queue to Submit</th>
<th>Submit to GPU Start</th>
<th>GPU Start to GPU End REAL WORK</th>
<th>GPU End To CPU End</th>
<th>Total</th>
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</thead>
<tbody>
<tr>
<td>Subsequent enqueue</td>
<td>28</td>
<td>19</td>
<td>137</td>
<td>12</td>
<td>32</td>
<td>231</td>
</tr>
</tbody>
</table>

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Current OpenCL™ scheduling model

- Driver overhead is significant:
  - Not suitable for small kernels.
  - Not suitable for low latency scenarios.

- Submission is expensive:
  - Memory needs to be resident.
  - GPU threads are created & destroyed for each kernel.

- Why queue if I want to submit?
  - No queue needed if 0 cost submission & completion.

Current scheduling model doesn't suit well for low latency / short workloads
Agenda

• Current OpenCL™ scheduling model

• **GPU Daemon:**
  - Instant Mode
  - Enqueue Mode

• Performance Data

• Efficient use of GPU Daemon patterns

• Summary
Introducing GPU Daemon

- GPU Daemon is a kernel launched from the host and later persistent on the GPU.
- It communicates with CPU using Fine-Grained Shared Virtual Memory with atomics.
- Persistency is achieved using various methods:
  - Instant Mode – loop within a kernel.
  - Enqueue Mode – self-enqueue utilizing device_enqueue.
- CPU communicates directly with active GPU threads bypassing driver stack.
- Whenever Daemon is no longer needed CPU sends “end” signal that will terminate GPU threads.
Introducing GPU Daemon – Instant Mode

Application
- clEnqueueNDRange
- clFlush
- Compute Request
- Leave Request

Graphics Driver Stack
- UMD Runtime
- KMD/OS
- SVM Communication Buffer

Graphics Processing Unit
- Threads Creation
- GPU Daemon
- End

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Instant Mode – tasks processing

CPU

New Compute Task

Work Done?

Yes

Data ready

No

SVM Communication Buffer

GPU

New Work?

Yes

Process work

No

Work Done Signal
GPU Daemon in Enqueue mode

- Enqueue Mode allows various different transitions:
  - Utilizes device self-enqueue feature of OpenCL™ 2.0.
  - GPU can switch to Instant mode for direct submission.
  - GPU can enqueue traditional kernels without the need of host API interaction.

- Gives great flexibility in terms of possible options:
  - Whole host code can be transferred to the device.
  - Various Instant kernels may be dispatched, serving different compute algorithms.
Introducing GPU Daemon – Enqueue mode

- CPU
  - Switch to Instant
  - Compute
  - Switch to Enqueue

- GPU
  - GPU Daemon Enqueue Mode
    - 1 HW thread
  - GPU Daemon Instant Mode
    - All HW threads

SVM Communication Buffer
Agenda

• Current OpenCL™ scheduling model
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Model Comparison – classic vs GPU Daemon

Application

Start

clEnqueueNDRange

clWaitForEvents

End

Graphics Driver Stack

UMD Runtime

Submit 137 us (59%)

Queued (28+19) us 20%

Graphics Processing Unit

GPU Start

Threads Creation

Threads Execution

GPU End

Signal

VS

Compute Request + Response

SVM Communication Buffer

GPU Daemon

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Kernel execution comparison (ns)

- Instant Mode Execution is faster than traditional enqueue (+5%):
  - No Thread Creation
  - No Thread Destruction
  - GPU boosted to high frequency
- This time includes CPU + GPU atomics communication cost for submission and completion.
- After work is done, threads are immediately ready for next submission.

No kernel execution overhead with CPU+GPU synchronization.
Mode Transition Latency (ns)

- Instant mode may be initiated from the host or from GPU Daemon in Enqueue Mode.
- Time needed to enter Instant Mode from the host is 160 us.
- Same operation from GPU Daemon being in Enqueue mode takes 58 us.
- Useful when multiple different instances of Instant kernels will be required.
Model Comparison – Instant with active Daemon

GPU Daemon is a very efficient technique for zero cost submission & completion.

- Time from start to completion of the compute task reduced **19 times**!
- This includes submission, processing and completion of compute tasks.
- All latencies are not present, immediate compute power available on demand.

![Graph showing Total Time (ns) comparison between Traditional and Instant methods with a 19x reduction in time.](image-url)
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Make sure you spawn all HW threads available

- Query Number of Execution Units using:
  
  `clGetDeviceInfo + CL_DEVICE_MAX_COMPUTE UNITS`

- Multiply it by number of hardware threads on each EU (typically 7, refer to device documents), this will give you total HW threads count, i.e. for Intel(R) HD Graphics 560:
  
  \[24 \times 7 = 168\] Hardware Threads

- Obtain SIMD size of your kernel using (8,16,32):
  
  `clGetKernelWorkGroupInfo + CL_KERNEL_PREFERRED_WORK_GROUP_SIZE_MULTIPLE`

- Compute global work size that will result in all threads being spawned:
  
  \[Gws[0] = SIMDsize \times \text{NumberOfHwThreads} = 32 \times 168 = 5376\]

- Make sure your LWS is a multiple of SIMDsize.

- Make sure your GWS is a multiple of LWS.
Play nicely with GPU

- Be cautious to not spawn more HW threads than device has.

- Choose Local Work Group Size that fits nicely into sub-slices:
  - Make sure number of HW threads per sub-slice is a multiple of HW threads per wkg.

- When using SLM(Shared Local Memory) / barriers choose bigger workgroup sizes to maximize SLM re-use:
  - Take into consideration that SLM is limited, so GPU may not spawn threads because of lack of free resources.
  - There is 64 KB per sub-slice for all workgroups, so if each uses 16KB then only 4 may be executed concurrently on this sub-slice.

- When Daemon is not needed terminate it to save power.
Be cautious with the amount of atomic operations

1) **DON'T** increment spin on every work-item:

```c
__kernel Worker(__global int* pCommBuffer)
{
    __global atomic_int *atomicCommBuffer = (__global volatile atomic_int*)pCommBuffer;

    atomic_fetch_add_explicit(  
        &atomicCommBuffer[SPIN],  
        1,  
        memory_order_seq_cst,  
        memory_scope_all_svm_devices );
    //do the work
}
```

1) **DO** Only single increment per thread

```c
__kernel Worker(__global int* pCommBuffer)
{
    __global atomic_int *atomicCommBuffer = (__global volatile atomic_int*)pCommBuffer;

    if( get_sub_group_local_id() == 0 )
    {
        atomic_fetch_add_explicit(  
            &atomicCommBuffer[SPIN],  
            1,  
            memory_order_seq_cst,  
            memory_scope_all_svm_devices );
    }
    //do the work
}
```

Implicit SIMD synchronization reduces the amount of atomics up to 32x.
Or even better, synchronize on Workgroup basis

```c
__private int Finish = 0;
__private int ReqPhase = 0;

//loop as long as you need to
while( Finish != 0 )
{
    //each work item needs to check for work
    ReqPhase = atomic_load_explicit(
        &atomicCommBuffer[PHASE],
        memory_order_seq_cst,
        memory_scope_all_svm_devices );
    //each work item needs to obtain flag
    Finish = atomic_load_explicit(
        &atomicCommBuffer[FINISH],
        memory_order_seq_cst,
        memory_scope_all_svm_devices);
    //do some work
}

//shared local memory keeps control variables
__local uint Finish;
__local uint ReqPhase;
ReqPhase = Finish = 0;
barrier( CLK_LOCAL_MEM_FENCE );
//setup done, now loop as long as you need to
while(1){
    //one work item checks for completion OR new work
    if( get_local_id(0) == 0 ) {
        ReqPhase= atomic_load_explicit( &SVMComm[PHASE],
            memory_order_seq_cst,memory_scope_all_svm_devices);
        Finish= atomic_load(&SVMComm[FINISH],
            memory_order_seq_cst,memory_scope_all_svm_devices);
        //obtain work info here and propagate to SLM
    }
    barrier( CLK_LOCAL_MEM_FENCE );
    //all work items are synchronized here
    if( Finish != 0 ) return;
    //do the work on all work items basing on SLM inputs
}
```

Atomic traffic reduced by the factor of workgroup size (up to 256x)
GPU Daemon Instant mode – Thread Spawn

CPU

// SVM communication buffer
std::atomic<unsigned int>* pCommBuffer = (std::atomic<unsigned int>*) pData;
size_t gws = m_NumberOfHWThreads *
kernelSIMD;
// use 4 HW threads per WKG to minimize atomic traffic
size_t HWThreadsPerWKG = 4;
size_t lws = kernelSIMD * HWThreadsPerWKG;
clEnqueueNDRange("InstantKernel", gws, lws);
clFlush();

// wait before GPU is ready, each thread will signal
while (pCommBuffer[SPIN] < m_NumberOfHWThreads);
// if we are here it means that GPU is ready for submissions on all HW threads

GPU

__kernel InstantKernel(global int* pCommBuffer) {
    // tell compiler we will need atomic operations
    global atomic_int * SVMComm = (global volatile atomic_int*) pCommBuffer;
    // each HW thread notifies that it is ready
    if (get_sub_group_local_id() == 0) {
        atomic_fetch_add_explicit(& SVMComm [SPIN], 1,
            memory_order_seq_cst,
            memory_scope_all_svm_devices);
    }
    // initialize SLM to use it later for workgroup communication
    local int Finish;
    local int ReqPhase;
    ReqPhase = Finish = 0;
    barrier(CLK_LOCAL_MEM_FENCE);
    // setup done, we may enter polling mode
//make sure atomics are used
std::atomic<unsigned int>* pCommBuffer = (std::atomic<unsigned int>*)pData;

for(uint i = 0; i < iterations; i++) {
    // trigger workload
    pCommBuffer[PHASE] = ++Phase;
    // wait before completion
    while(pCommBuffer[COMPLETE] < m_numWorkgroups);
    // data is ready GPU completed
    // re-init completion value for next iter
    pCommBuffer[COMPLETE] = 0;
}

// terminate Instant
pCommBuffer[FINISH] = 1;

uint Phase = 0;
while(1) {
    if(get_local_id(0) == 0) {
        Finish = atomic_load(&SVMComm[FINISH]);
        ReqPhase = atomic_load(&SVMComm[PHASE]);
    }
    barrier(CLK_LOCAL_MEM_FENCE);
    if(Finish != 0) return;
    if(Phase < ReqPhase) {
        // do some work, increment Phase
        Phase++;
        // now signal completion
        barrier(CLK_GLOBAL_MEM_FENCE);
        if(get_local_id(0) == 0) {
            atomic_fetch_add_explicit(&SVMComm[COMPLETE],
                                      1, memory_order_seq_cst,
                                      memory_scope_all_svm_devices);
        }
    }
}
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Summary

- GPU Daemon is a **very** efficient technique for direct submission.
  - Submission and completion driver overhead is eliminated.
  - Kernel execution is boosted.

- GPU Daemon offers various modes allowing very flexible application paradigms
  - Instant Mode for direct submission
  - Enqueue Mode whenever we need to switch between modes or enqueue other workloads that don't require direct submission

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